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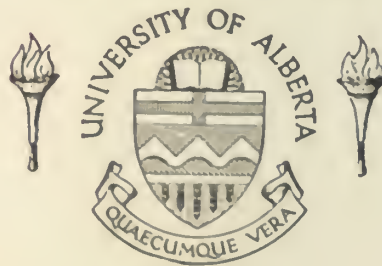
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THE UNIVERSITY OF ALBERTA

THE ELECTRICAL PURIFICATION OF WATER

A DISSERTATION

SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

FACULTY OF ENGINEERING

by

Keith Provost

EDMONTON, ALBERTA,

RESEARCH ON THIS TOPIC WAS CARRIED
OUT WITH THE AID OF A GRANT RECEIVED FROM
THE PRAIRIE RURAL HOUSING COMMITTEE AS A
PART OF THEIR RURAL SANITARY FACILITIES
RESEARCH PROGRAM.

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THE ELECTRICAL PURIFICATION OF WATER.

INTRODUCTION

A research investigation has been carried out to determine the possibility and practicability of employing electrical methods of producing potable waters from waters that possess too high a chemical salt for drinking purposes. The need for this is as follows:

(a) A considerable amount of water found on the prairies is very unsatisfactory for drinking due to too high a content of chemical impurities.

(b) While a number of experimental workers have tried electrical purification and have even produced water equivalent to distilled water, there has not been any authoritative statement on the practicability and economics of treating such water for household and dairy use.

Such a method of water purification would have several advantages:

(a) An electrical process could be made completely automatic, requiring little maintenance.

(b) It may have the advantage of improving the overall power load on rural electrification networks and thus help in their economic justification.

(c) The condition of life among the people affected could be improved in a number of ways;

1. The laxative effect caused by excess quantities of dissolved magnesium and sodium sulphate could be eliminated.

2. The detrimental effects which hard water has on human hair and on fabrics could be considerably reduced. (see footnote)

3. Scaling in cooking utensils, hot water heating coils, pipes, and farm engines could be reduced if not eliminated entirely. (see footnote)

4. Substantial savings could be made in the amount of soap required for all cleaning processes of the home, rural or urban.

Footnote: These latter effects are well illustrated on pages 1/10 and 1/11, Water Conditioning Handbook, The Permutit Company, New York.

HISTORY OF THE PROCESS

The electrical purification of water is by no means a new process. Patents for two diaphragm, three compartment cells for the electrical elimination of dissolved constituents from liquids, existed both in Britain and in Germany as early as 1903. Commercial cells for specialized applications were marketed under British patents by Elektro - Osmose G.m.b.H. Most of these cells were designed for the purpose of producing water equivalent to distilled water.

Dr. Jean Billiter presented two papers on the electrical purification of water to the Electrochemical Society, the first of these in 1931 and the second in 1936. At the time these two papers were presented, Dr. Billiter was a professor at the University of Vienna, Austria, and is now a consulting chemist in San Fransisco, California. In the first of these papers Dr. Billiter describes a one-compartment cell with which he was able to produce water equivalent to distilled water at a cost which was less than the cost of distilling the water by heat methods. The process, however, gave low current efficiencies and was adaptable to waters with less than 1000 parts per million of dissolved solids.

The second paper describes a three-compartment cell. Here again attention was focused on the production of water equivalent to distilled water. Waters containing less than 1000 parts of solids per million were purified to a salt content of 6 to 8 parts per million. Waters containing greater amounts of dissolved salts could first be subjected to treatment with zeolites before the

electrical process was applied. Commercial plants were built by Dr. Billiter, or on his licencees, which were capable of continuously producing desalted water with less than 10 parts dissolved solids per million parts of water.

Mr. R.E. Briggs, Consultant, Metropolitan Water District of Southern California, has designed a two compartment cell with a single diaphragm which will produce water "suitable for most industrial purposes." This cell (see fig. 1) depends on the electrochemical effects in the immediate vicinity of the cathode for its action. Calcium, magnesium and some other cations are precipitated in the cathode compartment due to the alkaline condition of the water. The water becomes alkaline due to the reaction of neutralized sodium ions with the water, forming sodium hydroxide. The outflow from the cathode compartment is subjected to settling and retention time and to filtration. The clarified water is then caused to flow through a segregated part of the anode compartment where the pH value is reduced. The anode solution of relatively high acid ion concentration is eventually discarded as a waste liquor.

Several industrial installations designed by Mr. Briggs have been operating successfully and one domestic unit has also given satisfactory service. The cell, however, has certain limitations. To date (1947) the process has been concerned with large scale production for municipal purposes and on waters difficult to treat by conventional methods. It was used on waters having impurities in the range between 1000 p.p.m. and 200 p.p.m. In commenting on the cell Mr. Briggs states, "Reduction of dissolved solids from 2000 p.p.m. to 500 p.p.m. would in most cases require both cation

and anion removal. Present developments do not indicate that this procedure would be practical for domestic usage."

Many of the waters in Alberta have dissolved solids far in excess of the upper limits of impurity which may be handled in the Briggs' cell. It was with a view to producing a domestic unit which will reduce the total salt content of water in the range 5000 p.p.m. to 500 p.p.m. or less, that this research was carried out. The approach was, as Mr. Briggs suggested, through a process involving both cation and anion removal.

THEORY OF THE ELECTRICAL PURIFICATION OF WATER

Early attempts at water purification by electrical methods were carried out with a view to producing water equivalent to distilled water. Purification by distillation involved the conversion of the entire mass of water into steam and then condensing it again into liquid water. Since the amount of dissolved substances is usually very small, in most cases only 0.2 to 1.0 percent of the water, it would seem more rational to carry out the purification by removing the small quantity of dissolved substances without touching the large mass of water. The fact that most of the impurities produce electrolytes makes it possible to apply electrical methods.

The three compartment cell has been used for this purpose with some success. The principle of water purification is the electrolytic transference of ions through diaphragms in cells with two diaphragms as shown in Figure 2. When a voltage is applied to the cell, which contains impure water in the three compartments, a current is carried between the electrodes by means of the ions present. Immediately upon closing the circuit, the cations present in the solution will move toward the cathode and the anions to the anode. As the ions move into their respective electrode compartments they will be discharged and will in general react with the water to cause the anolyte to become acid and the catholyte alkaline. Inasmuch as the mobility of the H-ions exceeds by far that of all other cations, and similarly the mobility of the OH-ions exceeds that of all other anions, these two ions will

be the chief carriers of the current. These ions will then move out of their respective compartments and recombine in the centre compartment to form undissociated water.

The ions which have moved into the electrode compartments may be removed from the cell by scavenging the compartments with a flow of the original impure water.

A DESCRIPTION OF THE EQUIPMENT USED

The Three Compartment Cell Using Porous Clay Diaphragms

As an initial approach to the problem, it was decided to use a three compartment cell using porous clay pots for the diaphragms and carbon electrodes arranged in a glass trough as shown in Figure 3. The voltage was applied as shown and a 32 volt motor generator set was used to supply a variable source of D.C. potential.

Measuring Apparatus

Determinations of the purity of the water were to be made using a Wheatstone conductivity bridge arrangement as shown in Figure 4. The source of A.C. voltage was an R.C.A. beat frequency audio oscillator adjusted to give 1000 cycles per second. To provide a visual detector for speed in making observations, the voltage across A.B. was fed into an audio amplifier. The amplified signal was then applied to a cathode ray oscilloscope. With this system of null detecting, balances could be obtained accurate to three figures on the Leeds and Northrup slide wire.

A 6 volt buzzer and a set of earphones were also provided for use with the bridge to enable us to make measurements in the field if it was found necessary.

The conductivity cell itself was purchased from the Central Scientific Company, and consisted of a set of circular platinum plates approximately 1 cm. in diameter and about 2 cm. apart, suitably mounted in a glass envelope to form a dip-type cell as shown in Figure 5a.

For reasons which will be discussed later, the three compartment cell using porous clay diaphragms, and the conductivity system of measuring were found to be unsuitable for our purposes and were set aside temporarily.

The Scavenged Electrode Cell

A new type of cell based on dialysis cell principles described in Volume 35 of the Journal of Physical Chemistry, page 1351, was suggested by Professor J.A. Harle. The cell shown in Figure 6 was built by the writer. Essentially it consists of a lucite cylinder and the two end plates of the same material. Mounted in the end plates are circular carbon electrodes. Electrical connections are made to the electrodes by means of two flexible brass discs mounted behind the electrodes. The electrodes, which were approximately $1\frac{1}{2}$ inches in diameter by $\frac{1}{4}$ inch in depth were held in place by cementing the edges to the walls of the well, which has been turned in the endplates. Ordinary household cooking parchment, placed over the electrodes and held in place by the lucite cylinder, formed a small compartment around each electrode. Holes and tubes were provided for circulating water through each electrode compartment. In order to obtain a voltage range from 0 to 125 volts, connections were made through a potentiometer to a 125 volt D.C. generator driven by a synchronous motor.

Measurements of dissolved solids were made by evaporating samples of water and weighing the residue. This method, though sufficiently accurate for our purposes, was very slow and cumbersome.

THE KIND OF WATER USED

In order to obtain some idea of the type of water likely to be found in the province, data obtained from water analysis records of the Provincial Analyst and of the Provincial Laboratory were studied. This data had been previously compiled in Report No. 68, Department of Animal Science, University of Alberta, by S.E. Beacom.

Graph No. 1 shows the cumulative frequency distribution of total dissolved salts in 343 samples of waters taken from various points throughout Alberta. Slightly more than 3 percent of the samples had total dissolved solids of more than 5000 p.p.m., while 75 percent had dissolved solids greater than 500 p.p.m. These samples are not necessarily a true cross section of all the waters to be found in Alberta. However, it does indicate the range of dissolved solids which will be met in practice. Tests were carried out using artificial samples with dissolved solids ranging from 500 to 5000 parts per million.

Once the range of the dissolved solids was established it was necessary to determine the relative abundance of the various ions which made up these dissolved solids. This was done to establish a standard water for use in these tests, which could be artificially made and at the same time be more or less representative of waters which one is likely to find in Alberta.

The analyses of 43 samples of water were studied and the results plotted in Graph No. 2. By using that percentage of total solids which occurred in the largest number of samples for each of the ions present, a standard water was established. This water was made up

of the following:

NaCl	1.73	percent of total solids			
MgSO ₄	7.77	"	"	"	"
CaSO ₄	21.30	"	"	"	"
NaHCO ₃	35.80	"	"	"	"
Na ₂ SO ₄	33.40	"	"	"	"

RESULTS OBTAINED

A Static Cell with Porous Clay Diaphragms

Initial tests were made using the arrangement shown in Figure 3 except that carbon electrodes (figure 5 b) were substituted for the electrodes shown. A potential of ten volts was applied to the electrodes. The electrolyte was originally at the same level in the three compartments and contained 4000 parts per million of Na_2SO_4 . The variations in conductance with time, of the electrolytes in each compartment are shown in Graph No. 3. As was expected, the conductance in the two electrode compartments increased with time, the rate of increase being greater in the anode compartment due to the greater equivalent conductance of the SO_4^{--} . Graph No 3. also shows that the conductance increased in the centre compartment. This was in direct contradiction to expectations, since it seemed that if ions were transferred from the centre compartment to each of the electrode compartments there would be a depletion of ions in the centre compartment and a consequent decrease in the conductance of the electrolyte.

It was suggested that this phenomenon could be due to impurities entering the electrolyte from one of the electrodes. The following test added to this possibility.

The carbon electrode which had been used for the anode was placed in one of the porous pots containing 1000 p.p.m. Na_2SO_4 solution and allowed to stand for two and one-half hours. The conductivity was measured at intervals and was found to increase noticeably.

This indicated that part of the anode was going into solution and may have been contaminating the electrolyte. This further indicated that a new electrode material was necessary. Stainless steel was selected and new electrodes were constructed as shown in Figure 5c.

Graph No. 4 shows the variation in conductance in the three sections over a period of 105 minutes. In this test a potential of 30 volts was applied to the stainless steel electrodes in an electrolyte containing 1000 p.p.m. of Na_2SO_4 . Here again the conductance in the three compartments increased although the conductance in the centre compartment did not increase as rapidly as previously. It was noticed that there was an electro-osmotic transfer of water out of the anode section and into the cathode section. The anolyte became a distinct orange color indicating that the anode material was going into solution.

Only the results of two tests have been mentioned here, but it should be said that a total of eleven tests were carried out using different potentials and different concentrations of electrolytes. Sodium sulphate was used in all but two of these tests. In these two tests standard water, as previously described, was used. The overall result was, however, similar to the two tests cited here as examples, that is, the conductance increased in all three compartments.

Each of the eleven tests mentioned above was a static test. No water was circulated through the electrode compartments to remove the ions as they came into the electrode section. Furthermore, due to the transfer of water by electro-osmosis, the hydrostatic head of the electrolyte in the cathode section was several inches above that

of the centre section. It was with a view to overcoming these objections that Professor Harle suggested the cell shown in Figure 6. In building the cell the object was to provide a means for scavenging the electrode compartments and at the same time keep these compartments as small as possible so that a relatively small amount of scavenging water would keep the salt content of the anolyte and catholyte at a minimum value.

Results with the Scavenged Electrode Cell

Graph No. 5 shows the results of a test using the scavenged electrode cell at a potential of 30 volts and with standard water containing approximately 1000 p.p.m. of dissolved salts. Distilled water was used to scavenge the electrode compartments. Due to the small size of the cell it was necessary to remove the water from the center section in order to make conductance measurements. This operation took less than a minute with the visual detector used and hence the time that the water was in the cell was not greatly different from those values indicated in the graph.

The conductance of the water in the cell decreased as shown, for over four hours at which time the conductance suddenly began to increase and continued to increase as long as the test lasted. It would appear that this sudden change in conductance also indicated a corresponding change in water purity. However, future tests contradicted this. Samples of water were placed in the cell for periods of two, four, and five hours and subjected to the same potential as the first sample. After each period, 50 c.c. of the water was evaporated to dryness and the residue examined. It could

be noticed, even without weighing these samples that the water continued to be purified even after the conductance began to increase after reaching a minimum value. The reasons for this change in conductance were not investigated. It was sufficient to know that conductance was not a good measure of the purity of the water and another method would have to be adopted. The method chosen was that of evaporating a known quantity of the water to dryness and weighing the residue. Besides being very cumbersome, this method had the disadvantage of requiring the entire cell contents to make a single salt content determination. In order to obtain a curve showing the variation in salt content of a given type of water over a period of time under a constant potential, it was necessary to prepare several liters of standard water at one time having the desired total dissolved solids. The salt content of this water was determined by evaporation of a small sample. Other samples were then placed in the dialysis cell for periods of $\frac{1}{2}$ hour, 1 hour, $1\frac{1}{2}$ hours etc. and subjected to the same potential in each case. After each period the sample was removed, evaporated and the residue weighed.

Results Using Evaporation Method of Measuring Salt Content

(a) Waters Used

The cell was filled for each test with 125 c.c. of standard water as previously described. Two series of tests were carried out using standard water showing a dry residue of 3300 p.p.m. in one case and 750 p.p.m. dry residue in the second case. The results of these tests are shown in Graph No. 6.

(b) Scavenging

The electrode compartments were continuously scavenged with water containing approximately 180 p.p.m. dissolved solids.

Because of the nature of the equipment used, the rate of flow of the scavenging water could not be maintained exactly constant. However, the rate of scavenging does not appear to be a critical factor in the electrical purification process and the objective here was to keep this rate at a minimum value to conserve water. The average rate of scavenging was about 300 c.c. per hour for both electrode compartments.

(c) Temperature

The average temperature at the beginning of each test was 24 degrees Centigrade. For the 3300 p.p.m. water, the temperature rose to a maximum value of 59.6 degrees Centigrade after one hour and gradually dropped to 33 degrees Centigrade after four hours. The corresponding maximum and minimum values for the 750 p.p.m. water were 36.2 and 28.8 degrees Centigrade.

(d) Diaphragms

Double thicknesses of parchment paper were used for each of the electrode compartment diaphragms. When these diaphragms had been in service for 5 hours, during which time the average current density was about 40 milliamps per square inch, a small hole appeared in the cathode diaphragm. All parchments were then replaced with new ones of the same material. The new diaphragms were in service for nine hours with an average current density of approximately 75 mils. per square inch when a hole appeared in the anode diaphragm. A third set of parchments were still intact after 6 hours with 75 mils. per square inch.

(e) Electrodes

Carbon electrodes were used for both the anode and the cathode for the entire set of tests. No deterioration could be

detected in the cathode carbon. The anode carbon, however, was dissolved continuously and washed out by the scavenging water. The current density varied considerably throughout the life of the electrode, but the average density was probably not more than 50 mils. per square inch. Originally the anode was $1\frac{1}{2}$ inches in diameter and $\frac{1}{4}$ inch in thickness. After a total operating time of about 64 hours the anode was reduced to one-half of its original size.

(f) Precipitates Formed

A flocculent white precipitate was formed in the center compartment in each of the tests. This precipitate could be seen to form during the first half-hour of each test; after that time it settled to the bottom and no further precipitate was formed. Measurements of salt content were made on samples of the water which had this precipitate removed by filtering. A white precipitate could also be seen in the water used to scavenge the cathode compartments.

(g) Energy Required

Graph No. 7 shows the variation in cell current over the test period of four hours for the 3300 p.p.m. water. The initial rise in current at the beginning of the test period is probably due to the change in conductivity of the scavenging water in the electrode compartments as the ions enter the compartments under the influence of the applied potential.

The energy required to reduce the salt content of the water from various levels (3300, 3000, 2500 etc.) to 500 parts per million was computed by finding the area under the current curve corresponding to the time required. Multiplying this area by 50 volts gave the energy in watt-hours. The energy was then expressed in terms

of kilowatt-hours per gallon of water and the results plotted in Graph No. 8. From this graph it can be seen that, for the cell used, one kilowatt-hour of energy is required to reduce the salt content of one gallon of water from 3300 parts per million to 500 parts per million.

(h) Voltage Distribution Between Electrodes

It was thought that decreasing the spacing between the electrodes may give rise to higher cell efficiencies. Accordingly the voltage distribution along the length of the scavenged electrode cell was obtained by inserting an electrode in a number of holes which had been drilled along the length of the lucite cylinder. The voltage between the end terminal and the electrode was measured in various positions by means of a high resistance vacuum tube voltmeter. Standard water containing 3300 p.p.m. dissolved solids was used in the cell. The applied potential was 50 volts. Graph No. 9 shows the voltage distribution at the beginning of the test and after one hour. The distribution after two hours was not shown since there was not an appreciable change over the distribution shown for one hour.

This plot shows that approximately 10 percent of the voltage drop occurs in the region of the cathode, 50 percent in the main body of the cell, and 40 percent in the region of the anode.

CONCLUSIONS

According to Faraday's law the quantity of salt removed from a sample of water should be directly proportional to the quantity of electricity which passes through the sample. Furthermore, since the voltage applied to the cell is constant, the quantity of salt removed for a given cell should be directly proportional to the energy consumed. Graph No 8, however, does not verify this since the curve of energy versus dissolved solids removed is not a straight line. This phenomenon is not peculiar to this particular cell, but, as Billiter indicates in his article¹, "The chief reason for this is that the ions that have migrated to the electrodes diffuse back into the body of the water." This is particularly true at the lower values of dissolved solids.

Practicability of the Process

The results plotted in Graph No. 8 indicate that the energy requirements for this cell are prohibitively high for its use as a domestic unit. If, for example, one was dealing with water containing 3300 parts per million dissolved solids, it would require one kilowatt-hour of energy to reduce the salt content of one gallon to 500 parts per million. Taking the cost of energy in rural areas as two cents per kilowatt-hour, and the total average water consumption including water for drinking, cooking and washing as 30 gallons per person per day, the cost of purifying this water would be 60 cents per person per day. Unless a much more efficient cell could be produced this cost would limit the use of this type of cell to specialized purposes where cost is not a primary consideration. The cell

may, however, be used only for drinking and cooking requirements where it is more a question of personal comfort rather than cost. In the example cited, only the energy cost has been considered. No allowance has been made for the cost represented by the scavenging water required, diaphragm costs and electrode costs. Consideration must also be given to the initial cost of a cell capable of producing sufficient water for domestic requirements.

Graph No. 9 indicated that additional economies may result from a shortening of the cell. To cite an example, it would seem that by using a cell with a length equal to 40 percent of the length of the cell used here, the energy could be reduced to approximately 0.6 K.W.H. per gallon and hence the output would be increased to 1.66 gallons per K.W.H., an increase of 66 percent. A cell which was 20 percent of the length of the existing cell should reduce the energy required to 50 percent of the present value and give an output equal to 2 gallons per K.W.H.

These figures are merely estimates based on the voltage drops found in Graph No. 9. Any authoritative statement would have to be based on tests carried out on actual cells with these shorter lengths.

Recommendations for Further Investigations.

(a) A Continuous Flow Cell

The cell used in the tests discussed in this report was a static cell in which a sample was placed, subjected to a constant potential for a certain time and then the sample was removed. This, of course, would not be practical in a domestic unit and further investigations should be carried on with a continuous flow cell. A continuous flow cell, besides being essential for a practical unit,

may give rise to higher efficiencies since Billiter indicates that "additional losses may occur when the current is not properly distributed due to poor circulation of the electrolyte in the middle compartment". Special consideration should be given to making such a cell fully automatic so that care and maintenance can be kept at a minimum.

(b) Potential

In order to develop a more efficient cell, tests will have to be carried out to determine the best potential to be used, having regard for the voltages available and auxiliary equipment, such as rectifiers, which would be necessary on a rural installation. The effect of a pulsating voltage as produced by a selenium rectifier should also be investigated.

(c) Anode Contacts

Approximately 40 percent of the voltage drop across the cell occurred in the immediate vicinity of the anode as compared to 10 percent at the cathode. The reason for this was revealed in an examination of the brass strip used to make contact to the carbon electrode. This strip was corroded to such an extent that it provided a high resistance contact to the carbon. Elimination of this resistance would undoubtedly lead to higher cell efficiencies.

(d) Materials

The several failures in the diaphragm material may indicate that a new material is required. However, these failures may have been due to purely mechanical injuries which the material received during installation. In this case it would be advisable to design a cell such that a membrane material was kept flat and unfolded.

Finding an anode material, which will not disintegrate in operation, is a problem of primary importance. A method of making contact to these anodes, is also needed.

The material used in constructing the cell itself is also important, but it is felt that a suitable plastic or bakelized paper material can be selected from the many types which now exist.

SUMMARY

Tests carried out using a scavenged electrode cell indicate that the energy requirements of such a cell make its use for all domestic purposes impractical in its present state of development. There are, however, indications bearing further investigations which may lead to a more efficient cell. These are:

- (1) Development of a continuous flow cell
- (2) Decreasing the length of the cell
- (3) Devising a lower resistance, non-corroding, contact to the anode

REFERENCES

1. Billiter Transactions of the Electrochemical Society, Volume LX, 1931, page 217
2. Billiter Transactions of the Electrochemical Society, Volume LXX, 1936, page 409
3. Holmes, H.N. and Elder, A.L. Journal of Physical Chemistry, Volume 35, A31, page 1351
4. Thompson Theoretical and Applied Electrochemistry
5. Briggs, R.E. Proceedings of Sixth Annual Water Conference, October 22-23, 1945
6. Ellis, S.B. and Kiehl, S.J. American Chemical Society, J 57 p.p. 2145-2149 November 1935
7. Tagg, G.F. Electrical Determination of Water Purity, Engineer 151, p.p. 532-534 May 15, 1931
8. Power p.p. 93 February 1950
9. Water Condition Handbook Permutit Company of Canada

Foreign References Not Available in the Library

10. Okuno, H. and Odake, V. Purification of Water by Electro-osmosis, Elektrot. Laborat., Tokyo, Japan Japan Researches circ. No. 331, p.p. 43, 1932
11. Electro - Osmotic Purification of Water - Soc. Franc. Bull. 2 p.p. 522, 540, ?ay 1932

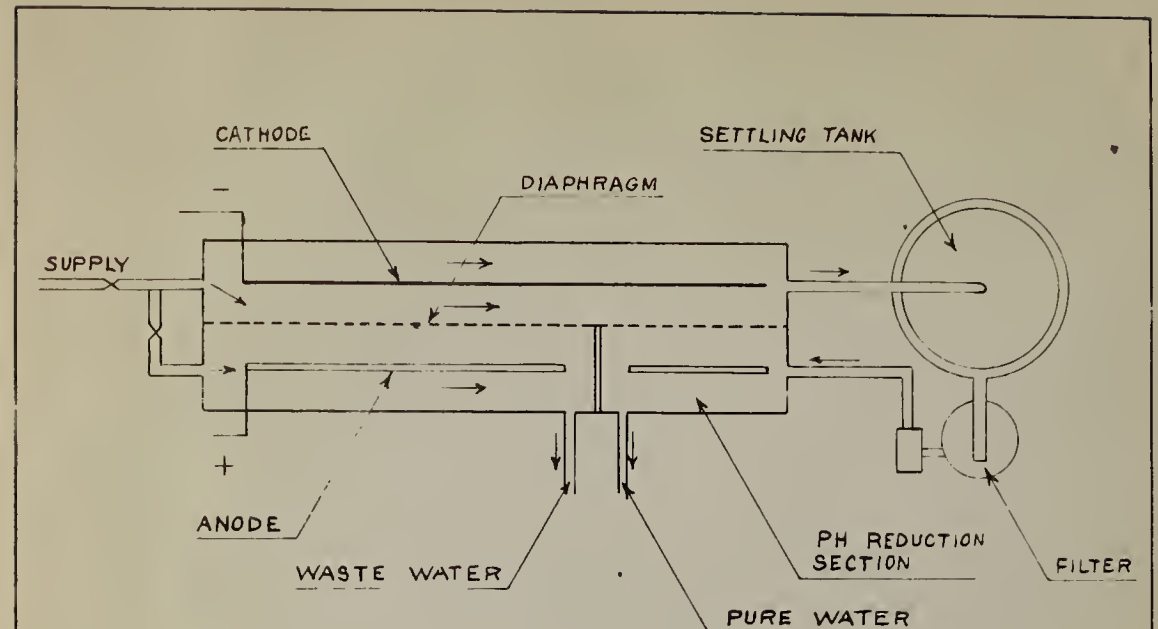


Fig. 1. Briggs' Two Compartment Cell

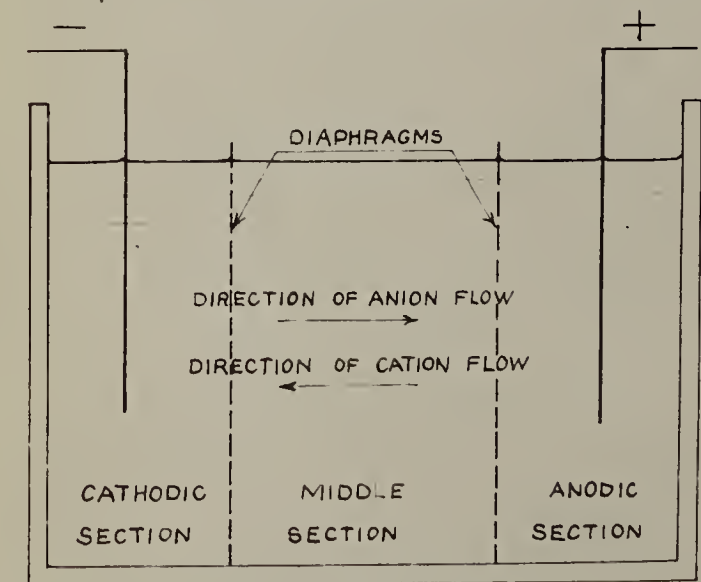
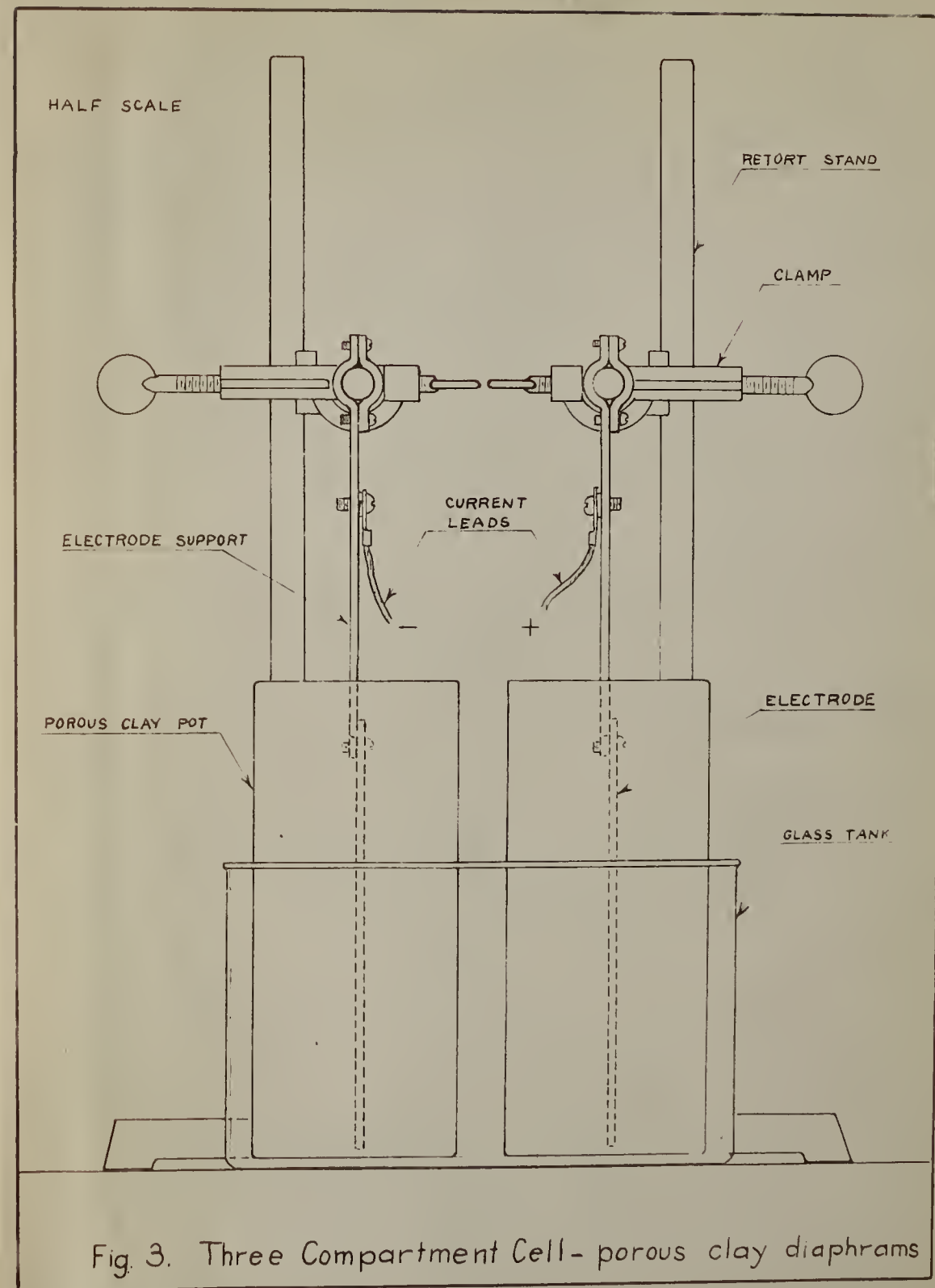


Fig. 2. Three Compartment Cell



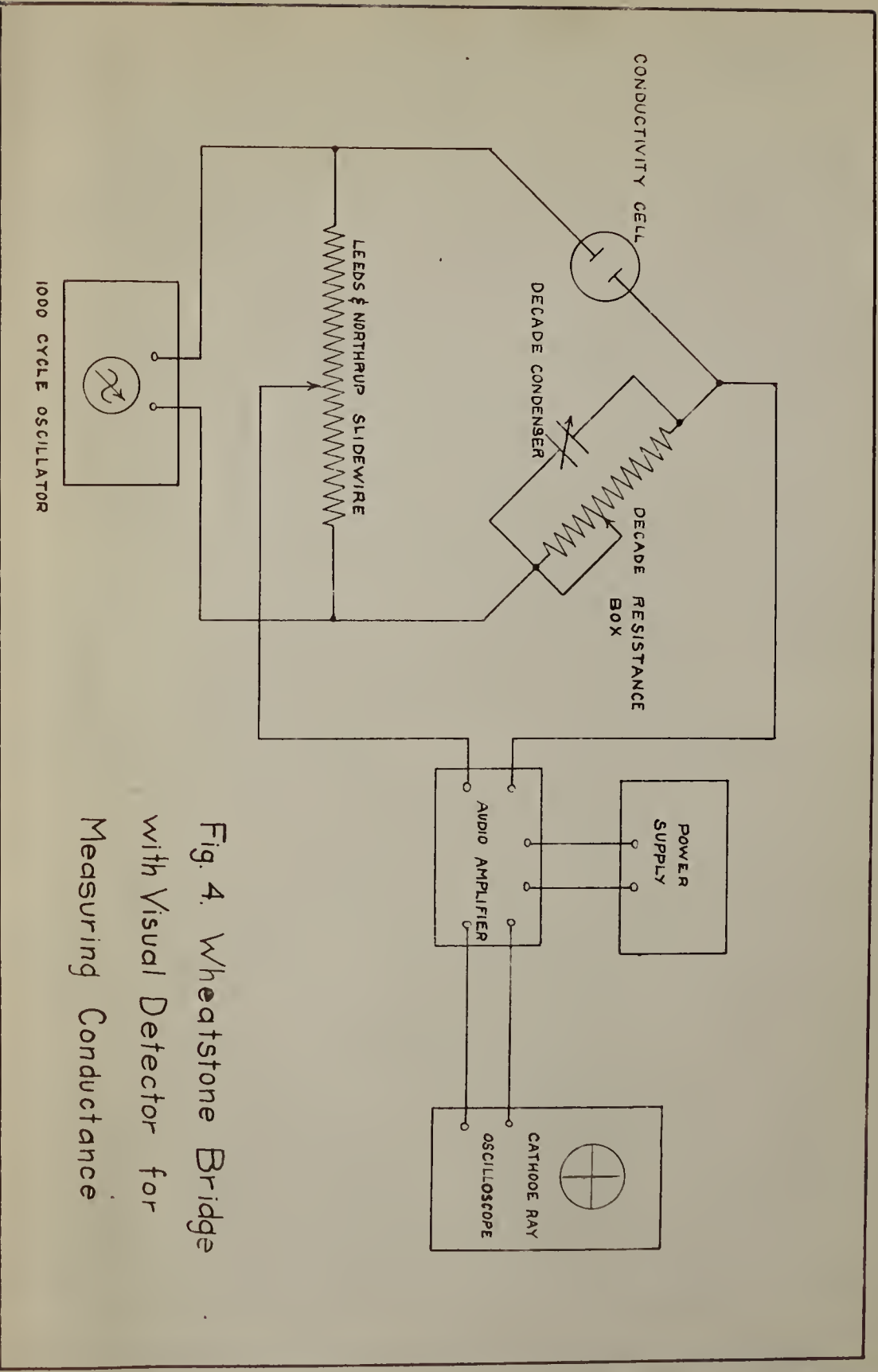


Fig. 4. Wheatstone Bridge
with Visual Detector for
Measuring Conductance

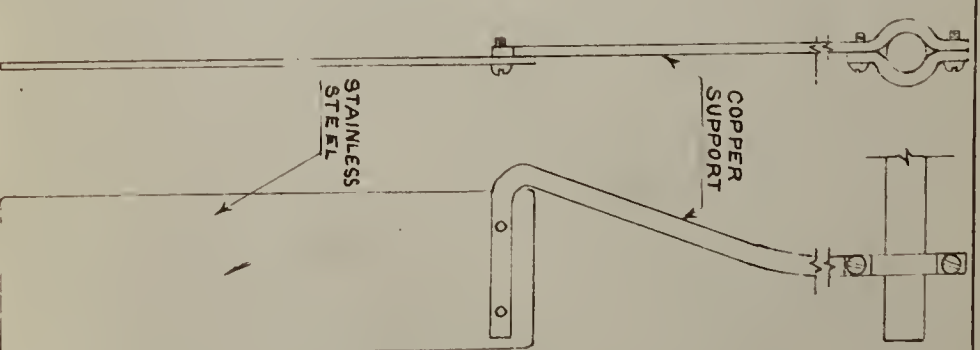
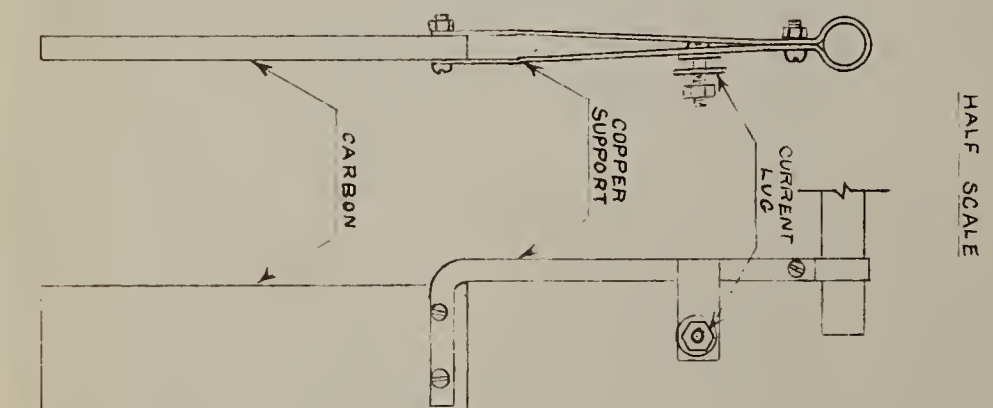
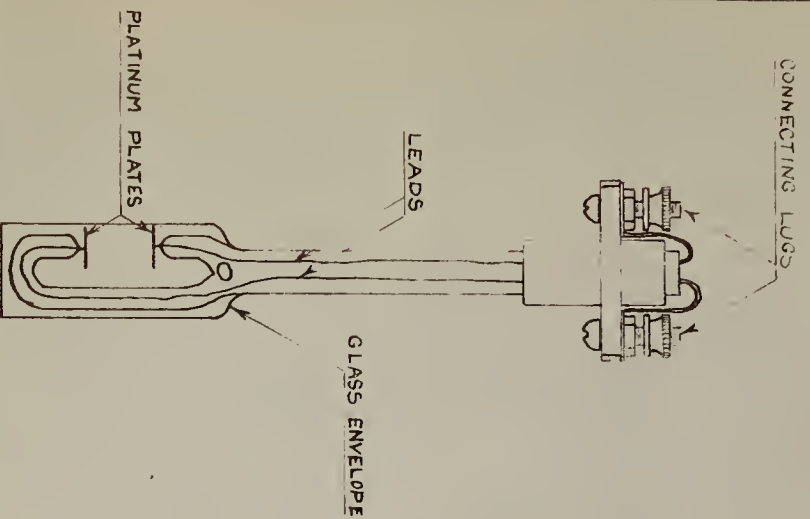


Fig. 5.

a. Conductivity Cell

b. Carbon Electrode

c. Stainless Steel Electrode

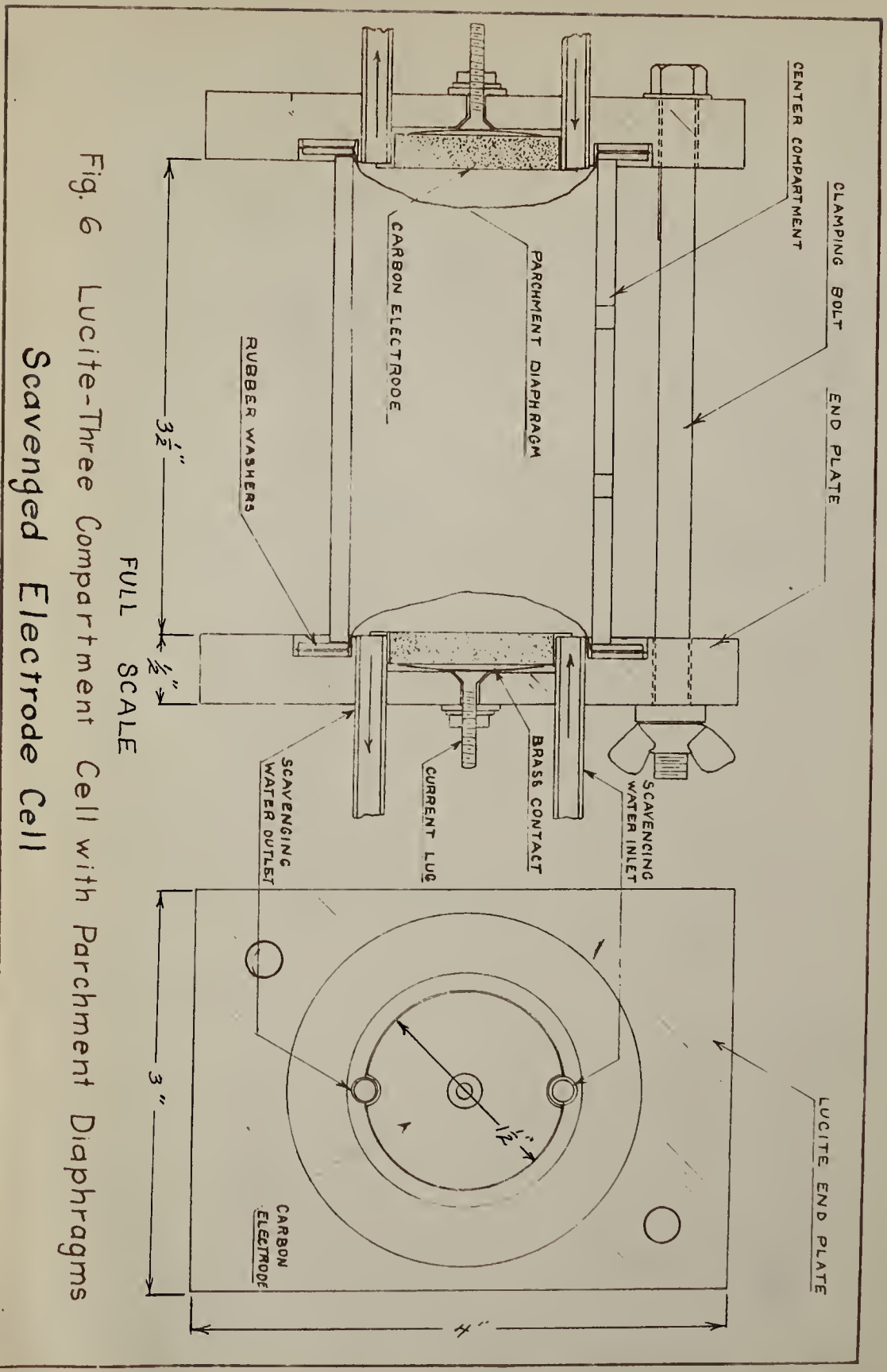


Fig. 6 Lucite-Three Compartment Cell with Parchment Diaphragms
Scavenged Electrode Cell

CUMULATIVE FREQUENCY DISTRIBUTION CURVE of Dissolved Salts in 343 Samples of Well and Surface Waters in Alberta

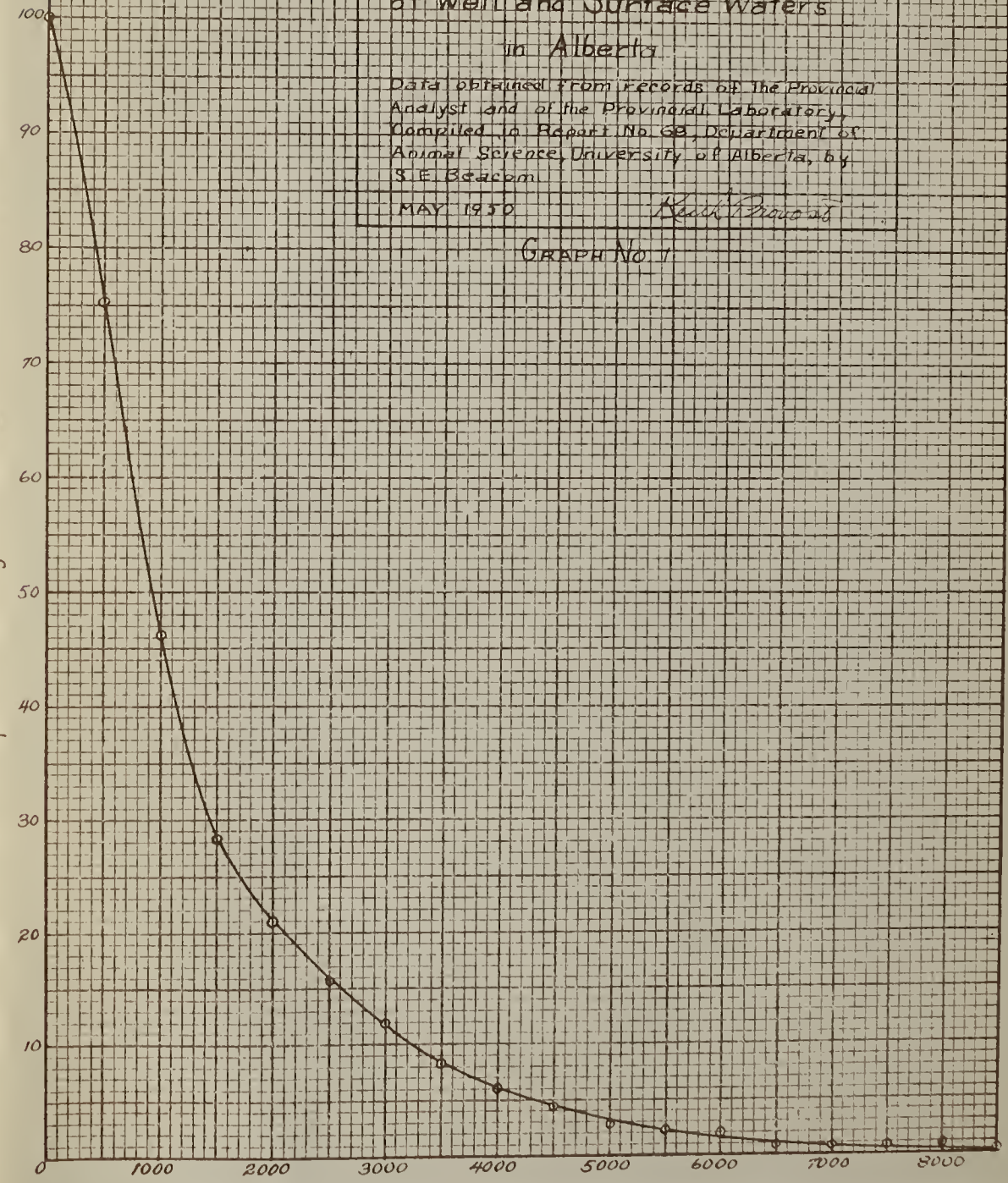
Data obtained from records of the Provincial
Analyst and of the Provincial Laboratory,
Compiled in Report No. 68, Department of
Animal Science, University of Alberta, by
S. E. Beacham

MAY 1950

Keith Provost

GRAPH No. 1

Percent of Total Samples Having Dissolved Solids Greater Than X



Dissolved Solids X, in Parts Per Million

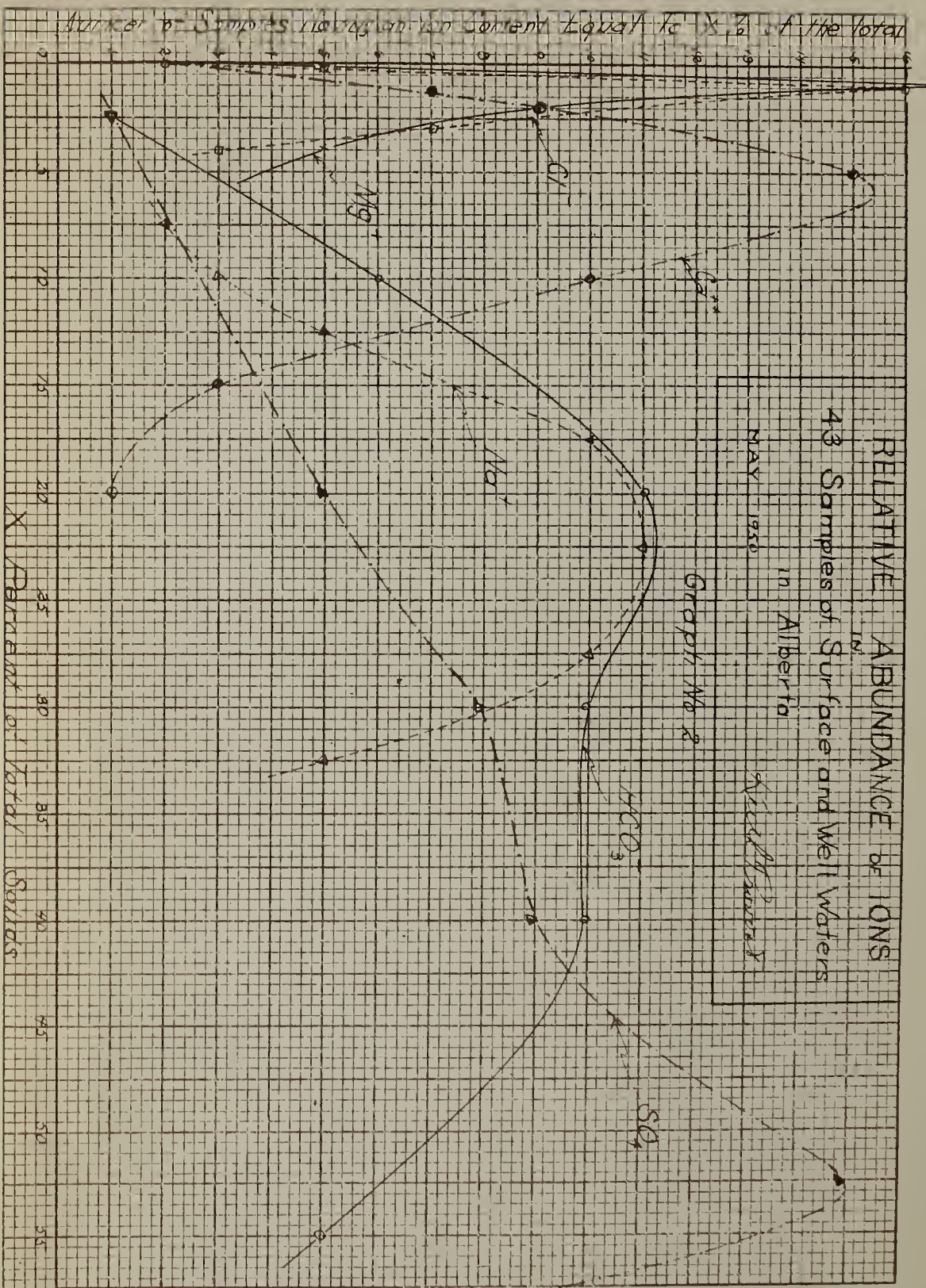
43 Samples of Surface and Well Waters

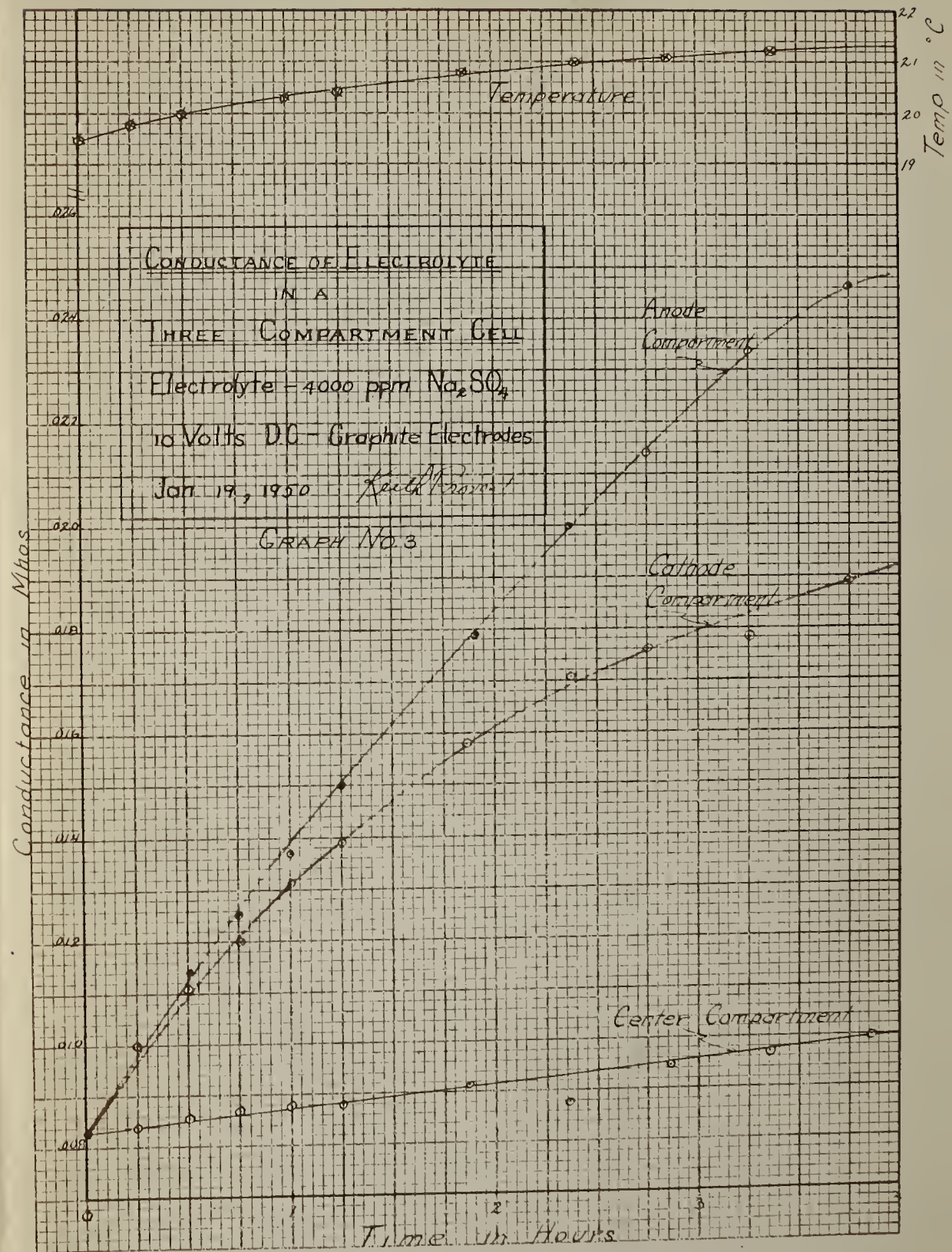
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CONDUCTANCE OF ELECTROLYTE IN A THREE
COMPARTMENT CELL

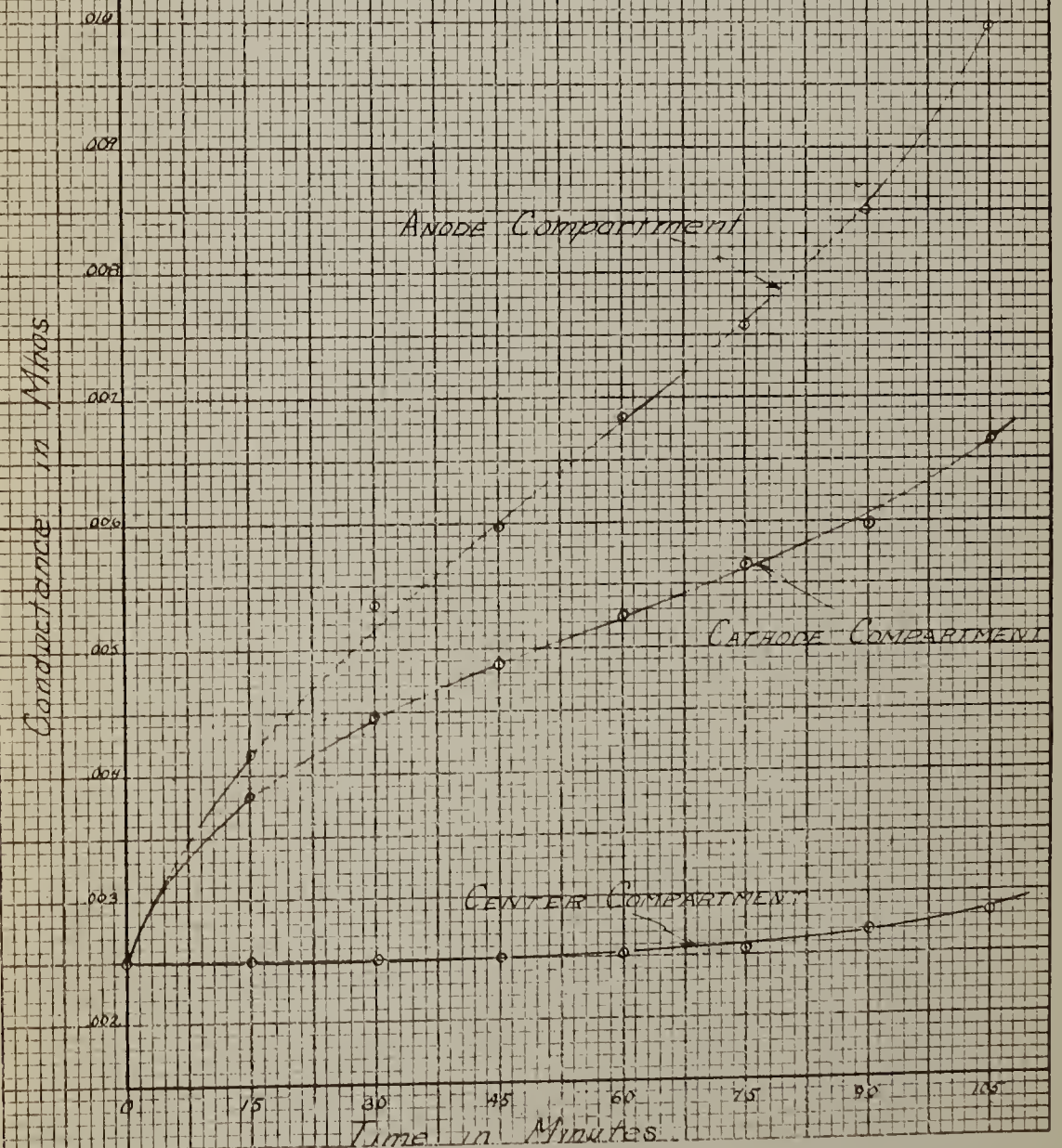
30 Volts Applied - Stainless Steel Electrodes

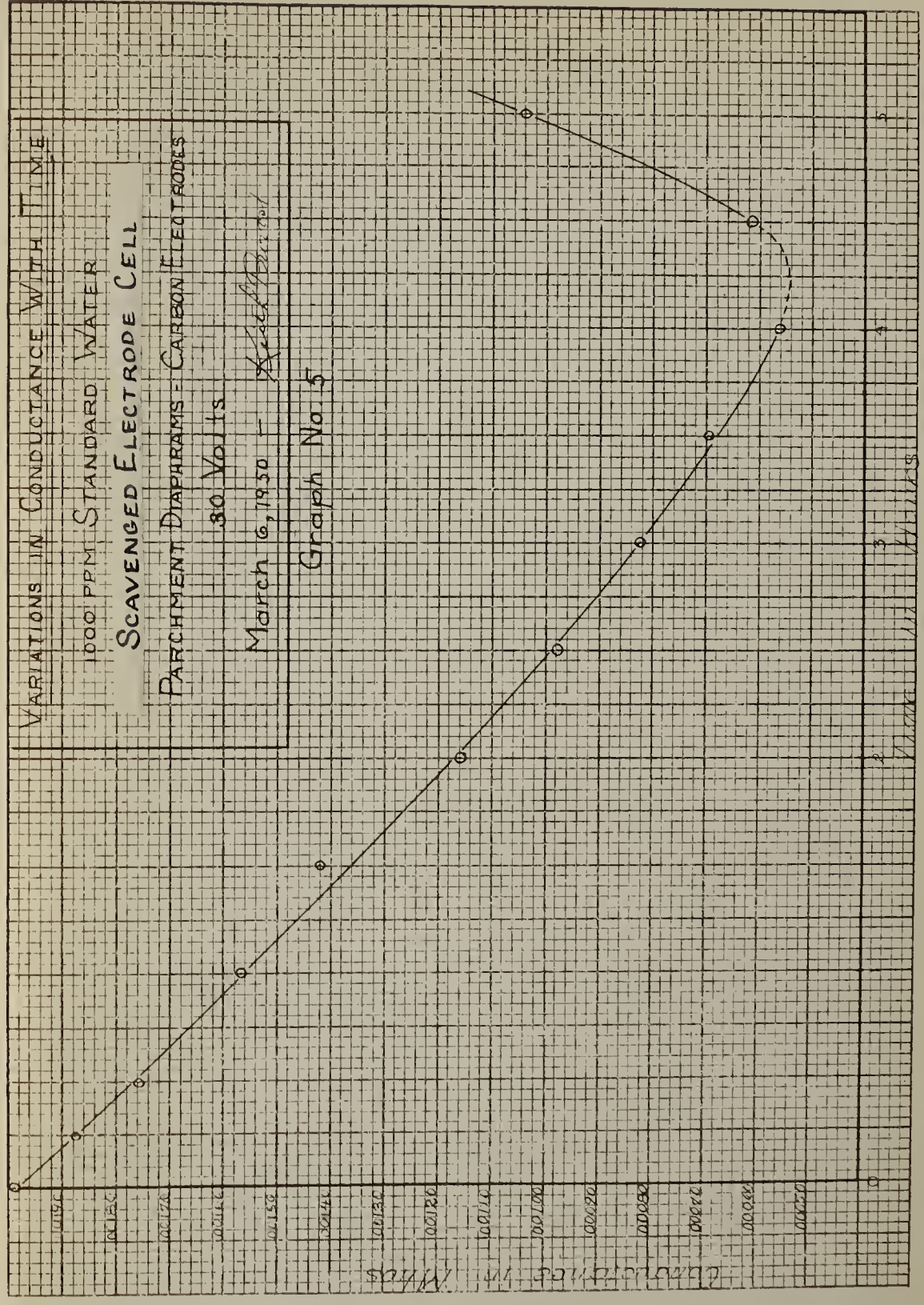
Original Electrolyte = 1000 ppm Na_2SO_4

February 13, 1950

Karl Pearson

GRAPH No. 4





ELECTRICAL PURIFICATION OF WATER

DRY RESIDUE VS TIME

STANDARD WATER SOLUTIONS

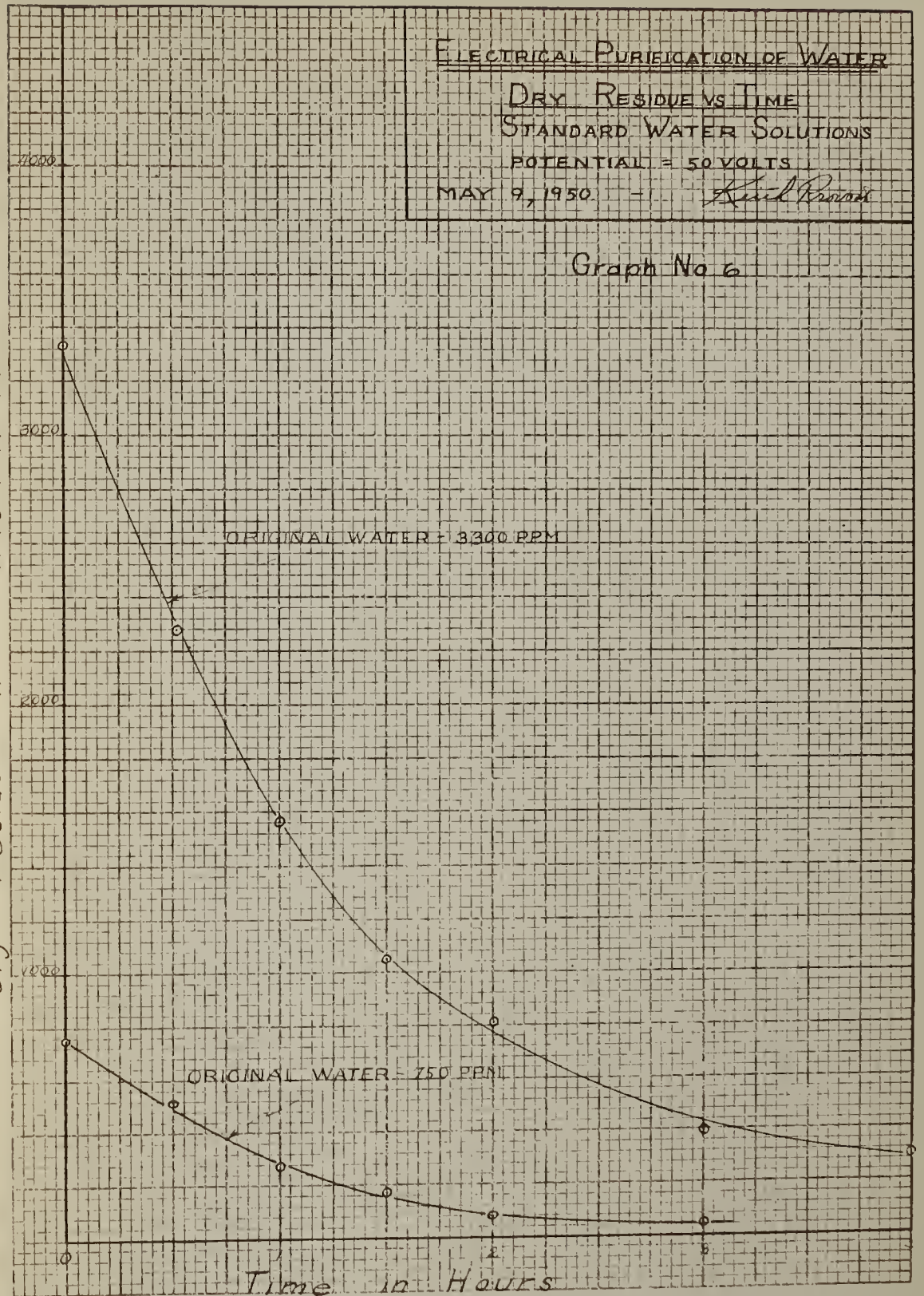
POTENTIAL = 50 VOLTS

MAY 9, 1950

Keith Russell

Graph No 6

Dry Residue in Parts Per Million



ELECTRICAL PURIFICATION OF WATER

VARIATION IN CURRENT

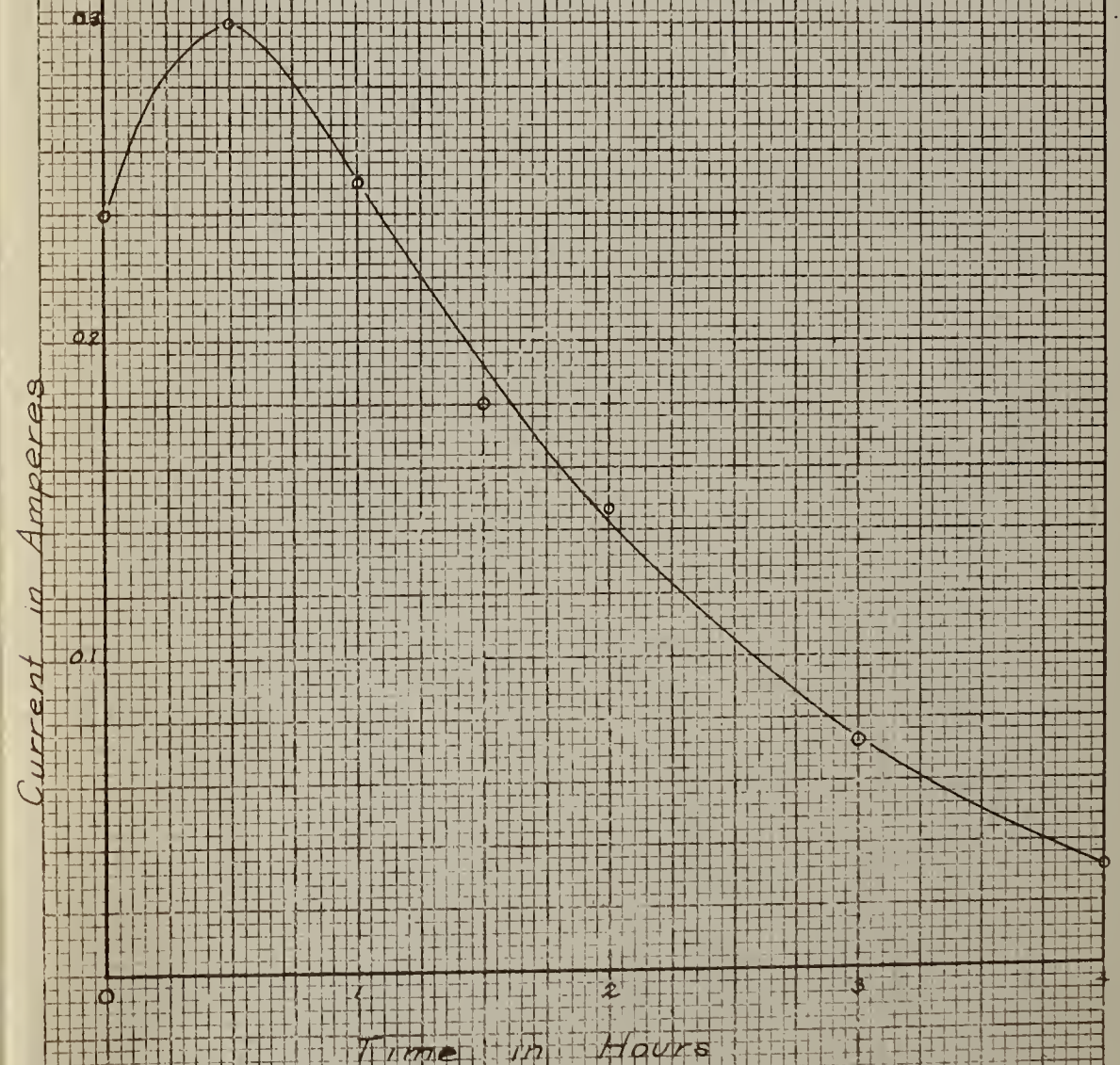
STANDARD WATER - 3300 PARTS

PER MILLION - DRY RESIDUE

POTENTIAL = 50 VOLTS

MAY 11, 1950 - *Karl P. Brown*

Graph No. 7



ELECTRICAL PURIFICATION OF WATER

POWER REQUIRED
TO REDUCE THE SALT CONTENT
OF STANDARD WATER
TO 500 PARTS PER MILLION

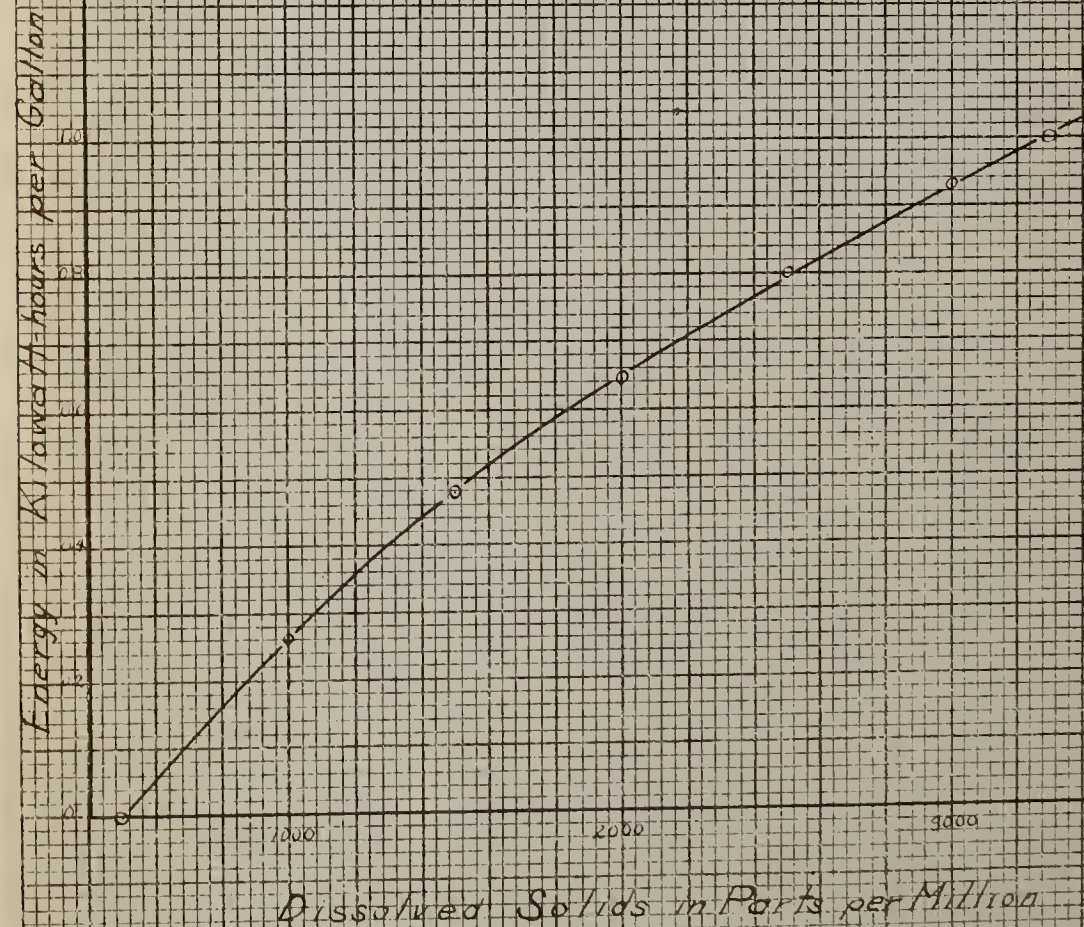
SCAVENGED ELECTRODE CELL

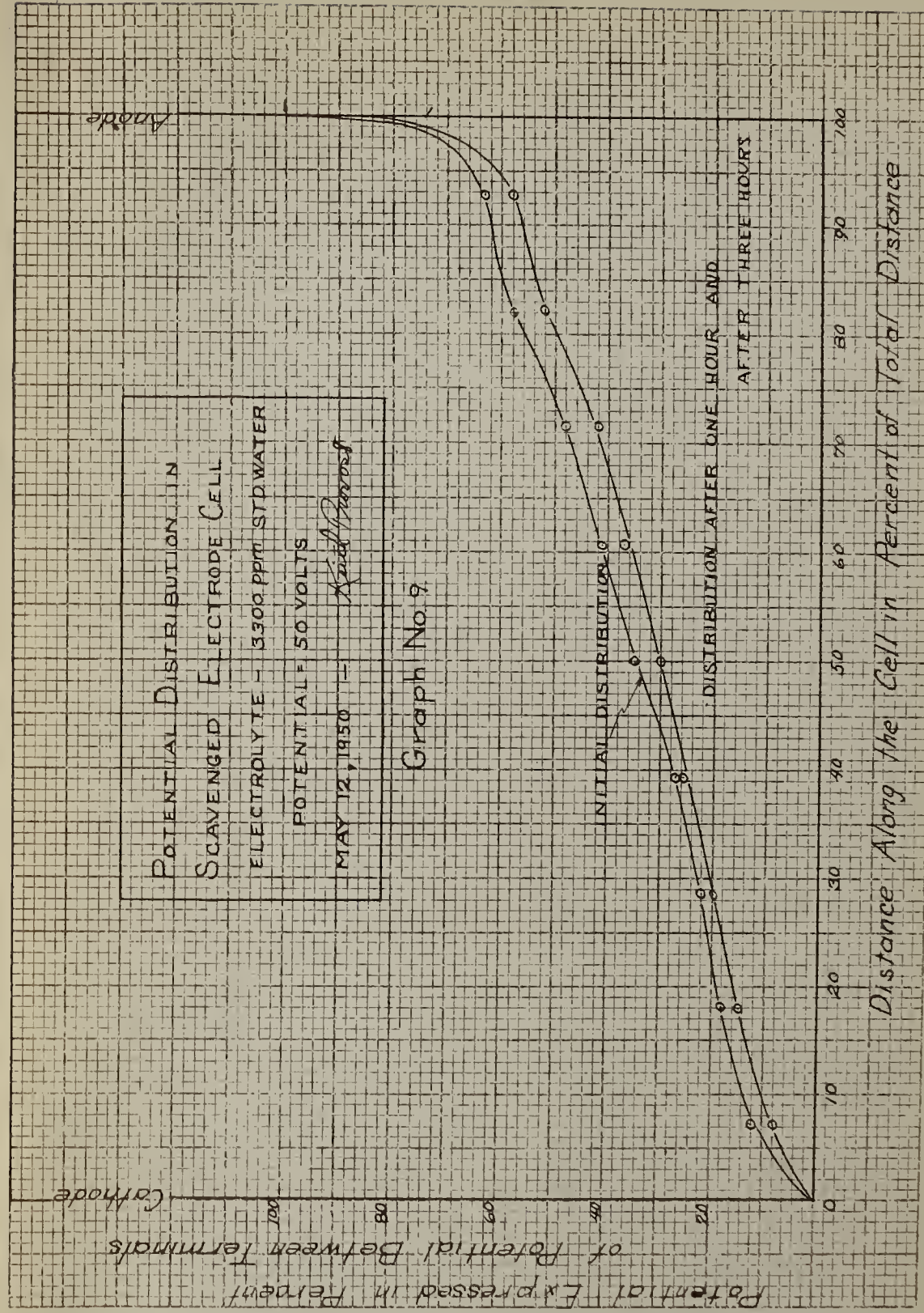
POTENTIAL = 50 VOLTS

MAY 10, 1950

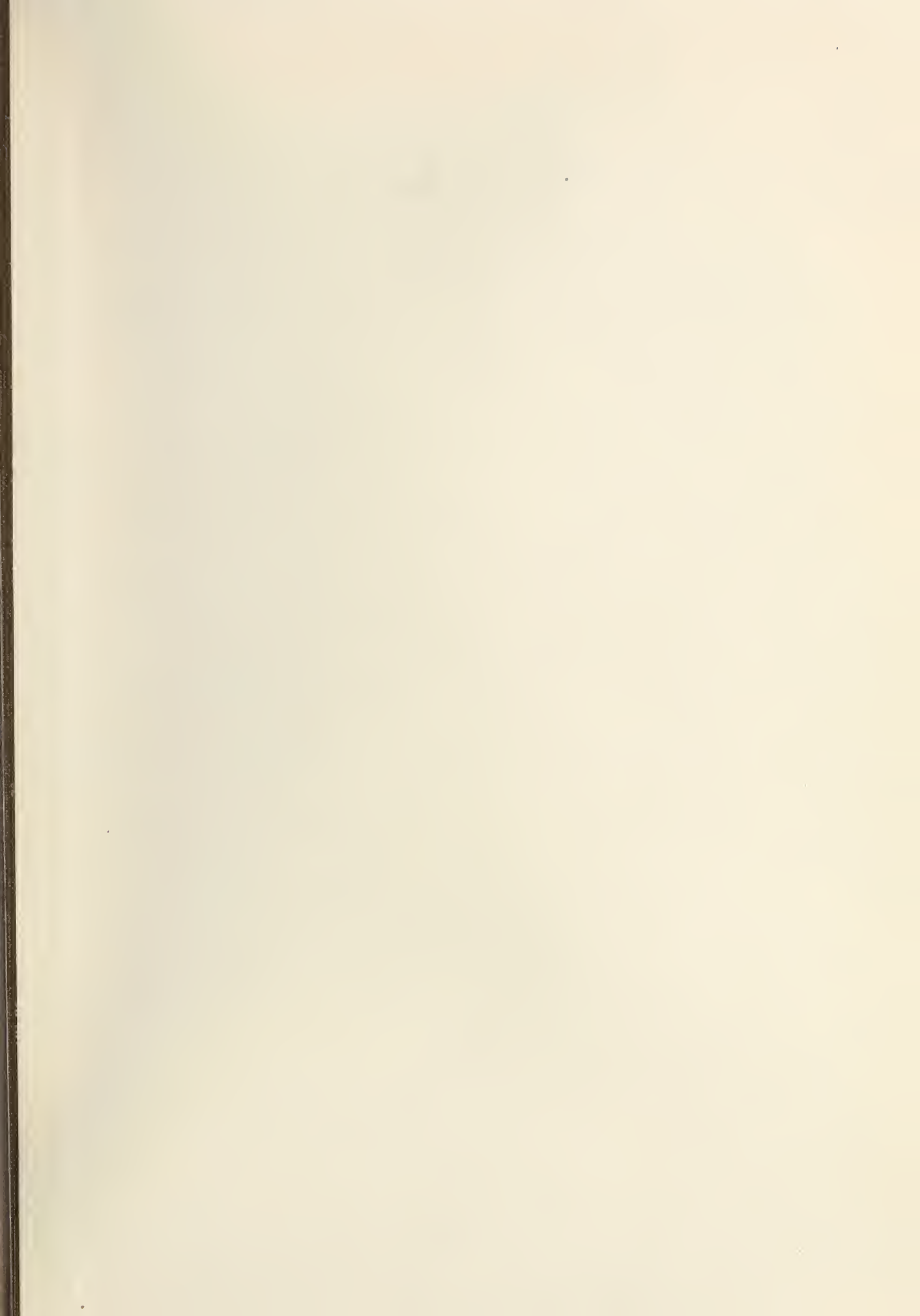
Karl Brown

Graph No. 3









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